COMPARISON OF STRETCH REFLEX TORQUES IN ANKLE DORSIFLEXORS AND PLANTARFLEXORS

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Abstract - **This study compared the intrinsic and reflex torques generated in response to position perturbations in tibialis anterior (TA) and gastrocnemius (GS) ankle muscles. Pulse, step, and a combination of random perturbation and step inputs were used to identify the reflex and intrinsic contributions to the measured torque. TA reflex torques were very small whereas GS reflex torques were substantial.**

Keywords – **reflex, intrinsic, stretch, dorsiflexor, plantarflexor, ankle, torque**

I. INTRODUCTION

The dynamic stiffness of a joint defines the relationship between the position and torque acting about it. It is important in the control of posture and locomotion since it contributes to the torques needed to maintain equilibrium or generate the movements necessary for walking. Stiffness has two components: an intrinsic component due to the mechanical properties of the joint, passive tissue, and active muscle fibers; and a reflex component due to muscle activation as a result of afferent response to stretch.

In the ankle joint, many studies have demonstrated that it is possible to separate the intrinsic and reflex components in the gastrocnemius (GS) muscle. For example, Kearney [1] used a parallel-cascade, nonlinear system identification technique and Sinkjaer [2] used a technique that eliminated the GS reflex torque by applying an electrical stimulation. Substantial reflex torques were seen in all these studies.

Determining the contribution of the tibialis anterior (TA) dynamics to the ankle joint is important to understand its role as an antagonist to the GS. However, few studies have measured TA reflex torques. Sinkjaer [3] eliminated the reflex response of TA by electrically stimulating the deep peroneal nerve. The intrinsic stiffness was subtracted from the stiffness measured with the reflex intact. The difference was used as an estimate of reflex stiffness which was found to be significant.

The purpose of this study was to contrast the reflex and intrinsic torques in the GS and TA using three different methods to measure the reflex torque.

II. METHODOLOGY

A. Experimental Protocol

Five normal subjects (four male, one female) participated in the study. Subjects lay supine with their left foot attached to a stiff, position-controlled electrohydraulic actuator by a custom–fit fiberglass boot. A potentiometer and torque transducer positioned in series with the actuator measured joint position and torque. Electromyograms of the TA and the GS muscles were recorded using bipolar electrodes.

All experiments were conducted with a joint position of zero (ankle at right angle) because this is the most important functional position. Subjects were trained to generate a low tonic contraction (5% maximum voluntary contraction) and instructed not to intervene with the perturbation. A target signal and a low-pass filtered torque signal were displayed. Three types of small amplitude (0.05 rad) position perturbations were applied to the subject:

1) *Pulse:* Brief pulses were applied in both the dorsiflexion (DF, stretching GS) and plantarflexion (PF, stretching TA) directions. Fifteen trials were recorded in each direction.

The rapid pulses stretched and returned the ankle to its original position before the reflex torque was generated (50 ms) so that the reflex could be measured without interference from the

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Abstract

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intrinsic component. However, the return to the original position evoked a reflex in the antagonist muscle (re-lengthening response).

2) *Step:* Step inputs of the same amplitude were used to avoid an antagonist response. To maintain a steady voluntary contraction with step perturbations, the torque feedback signal was 'frozen' following the step until the actuator returned to the starting position. Fifteen trials were recorded in each direction.

Response to step inputs had a sustained intrinsic component making the analysis more difficult. Consequently, we fit a 2nd order model to the first 50 ms of the response (which has no reflex component). Subsequent differences in the recorded torque and that predicted by this model are attributed to reflex.

3) *Combination:* Sinkjaer argued that the TA reflex may serve not to generate functional torque but to help linearize ankle stiffness [3]. If this is true, then the analytical separation method could give misleading results. To experimentally suppress the reflex and measure intrinsic torque, a combination of superimposed step and zero mean random vibration input was used. In GS, random vibrations are known to greatly reduce the reflex response [4]. The difference between the torque responses of step (intrinsic + reflex) and combination (intrinsic only) trials determines the reflex torque.

The random stimuli had a Gaussian distribution with maximum amplitude of 0.1 rad and zero crossing rate of 25 Hz. Thirty trials were recorded with this type of input.

B. Analysis Methods

For STEP inputs, the intrinsic torque was separated from the overall torque record by fitting a 2nd order linear model (1) to the early (non-reflex) step response.

$$T = I \cdot \frac{d^2\theta}{dt^2} + B \cdot \frac{d\theta}{dt} + K \cdot \theta \qquad (1)$$

Where T and θ represent ankle torque and position, respectively. I, B and K correspond to inertial, viscous and elastic parameters. K was first estimated by linearly regressing the torque and position records. The residual torque record was then regressed with the numerical derivative and second numerical derivative of the position record. Goodness of fit was evaluated in terms of percentage variance accounted for by the model. The intrinsic torque for the remainder of the response was then predicted by convolving the 2nd order model with the position record.

The reflex torque contribution (T_{reflex}) was quantified as the average difference between the intrinsic torque ($T_{j,intr}$) and the measured torque ($T_{j,meas}$).

$$T_{reflex} = \frac{\sum_{j=80}^{230} (T_{j,meas} - T_{j,intr})}{150} \qquad (2)$$

III. RESULTS

A. Pulse experiments

In response to the onset of a dorsiflexion pulse, GS EMG showed a burst of activity at 40 ms from onset of perturbation (Fig. 1D, dotted line) and a reflex response that peaked at approximately 160 ms (Fig. 1B, dotted line). A burst of activity was present in TA EMG at 90 ms (Fig. 1C, dotted line) apparently in response to the return to original position.

In response to a plantarflexion pulse, TA EMG showed a burst of activity at

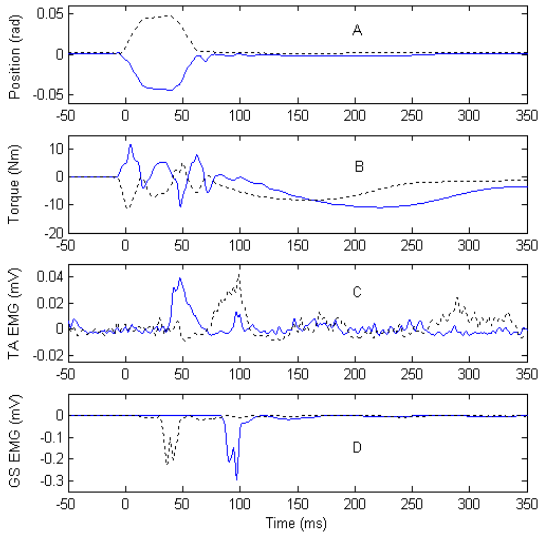

Fig. 1: Averaged dorsiflexion (dotted) and plantarflexion (solid) pulse trials (subject PF). A: Ankle position. B: Torque. C: Rectified and filtered TA EMG. D: Rectified and filtered GS EMG

approximately 50 ms (Fig. 1C, solid line), but no PF torque was observed (Fig. 1B, solid line). A burst of activity was present in the GS EMG at 100 ms (Fig. 1D, solid line). A corresponding reflex torque was elicited in the PF direction with a latency of approximately 170 ms (Fig. 1B, solid line).

B. Step experiments

In response to a dorsiflexion step, GS EMG showed a burst of activity at 40 ms (Fig. 2D, dotted line) and a torque response in DF was generated at approximately 155 ms (Fig. 2B, dotted line). No TA EMG activity was present (Fig. 2C, dotted line).

In response to a plantarflexion step, a burst of activity was present in TA EMG at 50 ms (Fig. 2C, solid line) but no torque was generated in the PF direction (Fig. 2B, solid line). No GS EMG was observed (Fig. 2D, solid line).

Fig. 3 shows the results from the analytical separation. Good fits to the early intrinsic response were observed in both the GS (Fig. 3A) and TA (Fig. 3B) step trials.

Table 1 shows the parameter estimates, percentage variance accounted (for both the early intrinsic and the complete time series) and calculated reflex torques.

Fig. 3 shows the predicted intrinsic torque (dotted lines) compared to the recorded torque (solid lines). Clearly, the reflex contribution (shaded areas) is considerably higher in GS (mean = 5.08 Nm, std = 2.29 Nm, N = 5) than in TA (mean = 0.47 Nm, std = 0.30 Nm, N = 5).

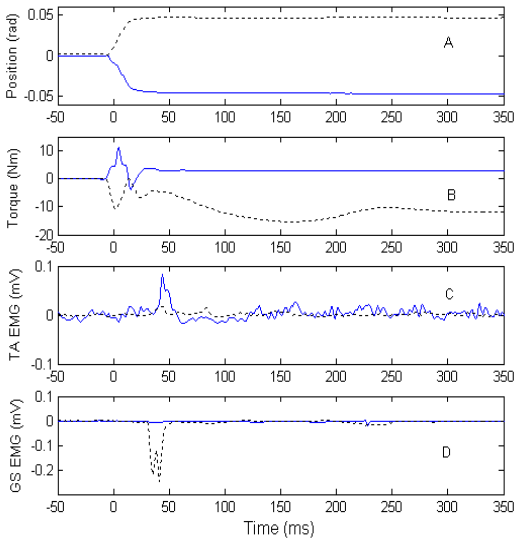

Fig. 2: Averaged dorsiflexion (dotted) and plantarflexion (solid) step trials (subject HL). A: Ankle position. B: Torque. C: Rectified and filtered TA EMG. D: Rectified and filtered GS EMG

C. Combination experiments

Fig. 4 illustrates an example of a direct comparison between the step (dotted lines) and combination trials (solid lines). The average difference between the step and combination trials was small indicating small reflex contribution (mean = 0.712 Nm, std = 0.47 Nm, N = 5).

The TA EMG (Fig. 4C) shows that the reflex is attenuated with random inputs, but not fully suppressed. Overall, the reduction in reflex EMG in TA due to vibration (mean EMG ratio = 65.6%, std = 29.5%, N = 5) was about half the reduction seen in GS (mean EMG ratio= 36.6%, N = 2, not shown).

Table 1: Analytical separation method statistics

Muscle		Parameters K	B	I	% VAF (Intrinsic)	% VAF (Total)	Average Reflex Contribution (Nm)
GS	mean	88.0	1.76	0.0189	93.9	61.6	5.08
	std	26.0	0.169	0.0030	2.1	8.9	2.29
TA	mean	48.2	1.57	0.0182	85.3	78.5	0.472
	std	13.3	0.207	0.0033	6.0	14.4	0.301

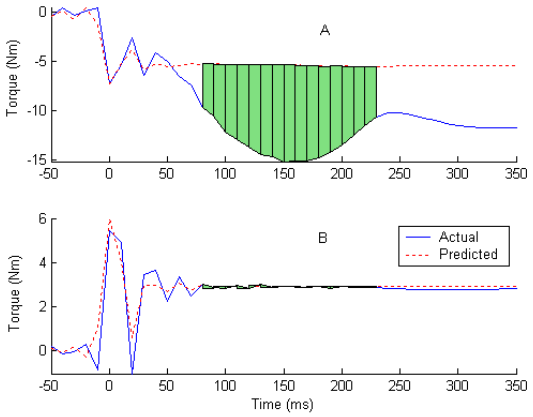

Fig. 3: Analytical separation: Comparison between step trials (solid) and intrinsic model torque (dotted). (Subject PF) A: GS step. B: TA step. Shaded area represents reflex torque.

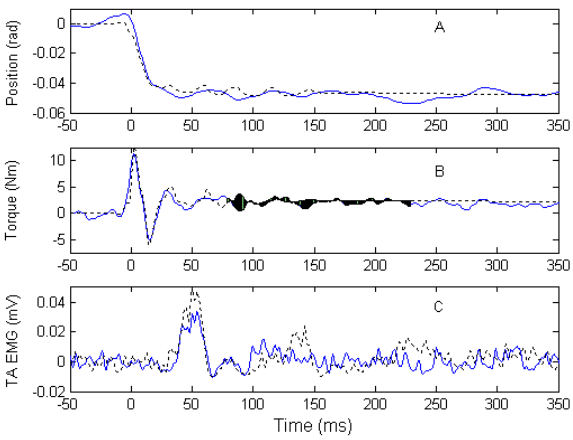

Fig. 4: Comparison between step (dotted) and combination (solid) trials (subject JT). A: Ankle position. B: Torque. Shaded area represents reflex torque C: Rectified and filtered TA EMG.

IV. Discussion

The key finding of this study is that there is no substantial reflex torque in TA. The step stretches elicited an EMG response, but no torque was generated.

One explanation lies in the EMG amplitudes. The mean reflex EMG evoked by step inputs is very small in TA (11% of MVC), relative to the EMG response in GS (167% of MVC). With such small EMG activity, we would not expect to observe meaningful torque generated by TA.

The results of this study confirm Sinkjaer's conclusion [3] that ankle stiffness behaves linearly in the TA direction. However, our findings do not show any reflex EMG contribution to this behaviour.

The lack of TA EMG suppression in combination trials may explain the lack of measured reflex torque and makes the interpretation of these results difficult. To elucidate these findings, further studies are needed to determine a more effective method of suppression.

Since reflexes are known to be highly task-dependent [5], it is possible that reflex torques may be observed in an upright posture. Initially, we scanned through ankle positions ranging from –0.1 rad to +0.1 rad and found no position dependence in TA reflex torque and TA EMG. In a more functional posture, such as standing, the TA reflex may be position dependent.

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VI. References

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